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MILTON WHITNEY, Chief.

EFFECTS OF SHADING ON SOIL CONDITIONS.

BY

J. B. STEWART.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., November 28, 1906.

Sir: I have the honor to transmit herewith an article entitled "Effects of Shading on Soil Conditions," by Mr. J. B. Stewart, of this Bureau. While the shading of certain crops has been practiced for a number of years, I am not aware that any comparative study has been made of the atmospheric and soil conditions arising from the use of cloth for this purpose. The data given in this manuscript cover this field of inquiry and should prove of value both to investigators and agriculturists. I therefore recommend the publication of this article as Bulletin No. 39 of this Bureau.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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EFFECTS OF SHADING ON SOIL CONDITIONS.

INTRODUCTION.

This bulletin contains the results of observations, made in the course of tobacco experiments in the Connecticut Valley, on the climate and soil conditions as affected by the tents used in producing the Sumatra wrapper type of leaf.

The tent method was first used in the production of tobacco in the Southern States, a little more than a decade ago, by some prominent tobacco men of New York City, who were desirous of improving this product. Its use was at first limited to a few acres in Florida. The new method gained ground slowly, but the marked rapidity of growth and the earliness of maturity of the plants thus treated made their product more like that of the tropical zone, and thus more valuable, a fact which practical men were not slow in recognizing. In consequence of this the industry spread rapidly until now it has reached many States of the Union, as well as Cuba and Porto Rico. The use of tent or slat shades has also been extended to the growing of pineapples and some truck crops.

It has long been recognized that the tent has a marked effect on the soil and atmosphere, as well as on plant growth, and this Bureau, in 1901, made some preliminary observations to determine the differences in open and tent production in the Connecticut Valley; but owing to the incompleteness of the records and the abnormal character of the season the results were not published. In 1905, however, an opportunity presented itself for a more thorough study of the subject, the records of which are given here.

Before attempting to discuss these observations it is necessary that a brief outline of the methods employed be presented.

The observations were made in conjunction with the practical tobacco investigations being carried on in the Connecticut Valley. (See Pl. I.) The records were taken during the growing season of 1905, from June 13 to August 5, inclusive, on one of the largest and best equipped tobacco plantations in the Connecticut Valley, located in East Granby Township, Hartford County, Conn.

Tobacco has been grown on this plantation for four successive years, and during that period all the land has been treated alike, as to fertilization, cropping, and cultivation. The land being level and of an even texture, was also favorable to the securing of trustworthy results. These facts eliminate the possibility of the difference in soil moisture being attributed to some other cause than the tent. Part of the 50-acre field was covered by a tent in which the records were taken. Observations were made also just outside.

SOIL MOISTURE.

The soil is described in the Report on Field Operations of the Bureau of Soils, 1903, as the Hartford sandy loam. It is one of the best types of soil in the Connecticut Valley for tobacco production.

The moisture content of this soil, both in and out of the tent, was determined every day from June 13 to August 1, inclusive. The instruments used (see Pl. II) were a soil sampler, screw-top tin cans, aluminum drying dishes, a torsion balance, and an oil stove and oven.

The soil sampler is a brass tube 13 inches long and 1 inch in diameter, one end of which is supplied with a sharp steel band, so that it can be driven into the earth with greater ease. In taking the sample the tube is pushed into the soil to the desired depth, then lifted, inverted, and its contents pushed out at the other end. In determining the moisture content of the soil, both inside and outside of the tent, four different places were selected, and samples drawn from each to avoid the possibility of testing soil taken from an exceptionally wet or dry spot, and thus obtaining an incorrect representation of the soil moisture of the area. A sample was first taken from 0 to 3 inches, then from 3 to 6 inches, and from 6 to 9 inches, both for outside and tented conditions. These samples were at once placed in screw-top tin cans and carried to a laboratory near by, where their moisture content was determined in the following manner:

The samples taken from the four parts of the field for each succeeding depth were thoroughly mixed and 100 grams carefully weighed in an aluminum dish on a torsion balance. These weighed samples were then placed in an oven heated to 212° F., where they were left three hours. They were then removed, cooled, reweighed, and the loss of weight taken as the moisture content of the soil.

The determinations were made separately for the samples at the several depths, the average for the three being taken to represent the moisture content of the soil.

The moisture content of the soil as determined from day to day for both inside and outside of the tent is recorded in the following table, which also gives the rainfall during the season:

TABLE I.—*Proportion of moisture contained in the soil inside and outside the tent, season 1905.*

Date.	Inside tent.				Outside tent.				Rainfall.
	0 to 3 inches.	3 to 6 inches.	6 to 9 inches.	0 to 9 inches.	0 to 3 inches.	3 to 6 inches.	6 to 9 inches.	0 to 9 inches.	
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Inches.*
June 13	15.4	15.5	14.9	15.2	17.2	17.3	16.7	17.1	0.65
14	16.8	16.5	16.7	16.6	14.8	15.3	15.8	15.3	.60
15	16.2	17.1	16.3	16.5	14.7	15.2	16.9	15.6	....
16	15.6	16.8	16.2	16.2	14.4	14.8	15.6	14.9	....
17	15.4	16.5	16.8	16.2	13.2	14.9	15.9	14.7	....
18	14.8	15.5	16.0	15.4	13.3	13.5	15.0	13.9	....
19	14.3	14.8	15.6	14.9	12.5	13.9	15.8	14.0	....
20	15.0	15.3	15.8	15.4	13.9	14.3	15.0	14.4	.10
21	15.5	15.9	15.1	15.5	14.1	14.3	15.1	14.5	....
22	17.2	17.1	17.0	17.1	17.1	16.7	17.2	17.0	1.54
23	15.7	16.6	17.3	16.5	17.0	16.4	17.6	17.0	.17
24	15.3	16.0	16.1	15.8	15.3	16.1	16.6	16.0	....
25	15.4	16.4	17.4	16.4	15.1	15.8	14.8	15.2	....
26	14.3	15.8	15.9	15.3	13.0	15.1	13.2	13.7	....
27	14.3	15.8	16.6	15.5	13.2	16.0	15.5	14.9	....
28	13.9	15.4	15.3	14.8	11.2	13.9	13.8	12.9	....
29	14.8	15.4	15.8	15.3	10.8	13.4	14.5	12.9	....
30	13.2	14.1	14.0	13.7	10.6	12.4	13.3	12.1	....
July 1	15.2	15.9	15.9	15.6	12.3	14.0	14.7	13.6	.22
2	15.0	15.7	15.5	15.4	13.3	14.1	14.8	14.0	....
3	15.2	15.9	15.0	15.3	13.4	14.6	14.9	14.3	.03
4	13.7	15.1	16.0	14.9	11.5	13.7	15.0	13.4	....
5	12.8	13.8	15.0	13.5	9.9	12.7	13.7	12.1	....
6	12.1	14.5	15.1	13.9	9.7	11.7	14.2	11.8	....
7	12.0	15.0	15.1	14.0	8.4	11.3	12.9	10.8	....
8	12.2	14.1	13.0	13.1	7.8	11.6	12.2	10.5	....
9	11.5	13.7	13.8	13.0	6.9	10.7	11.8	9.8	....
10	11.0	12.6	14.7	12.7	6.3	8.9	11.1	8.7	....
11	13.5	13.5	14.3	13.7	11.0	11.1	13.4	11.8	.17
12	12.2	13.4	14.6	13.4	9.6	11.4	13.0	11.3	....
13	10.7	12.3	14.3	12.4	6.6	9.1	9.8	8.5	....
14	10.1	11.8	13.7	11.8	6.2	8.7	9.6	8.1	....
15	14.5	13.3	14.0	13.9	11.9	11.3	13.2	12.1	.44
16	13.9	13.7	14.1	13.9	10.5	11.0	12.8	11.4	....
17	13.8	14.1	14.6	14.1	9.8	10.4	11.9	10.7	....
18	13.0	13.8	14.8	13.8	9.0	9.8	11.2	10.0	....
19	12.4	13.7	14.5	13.5	8.1	8.6	10.1	8.9	....
20	11.8	13.6	14.8	13.4	6.3	7.9	9.2	7.8	....
21	11.1	13.6	15.7	13.4	4.0	7.5	8.0	6.5	....
22	11.1	14.0	15.2	13.4	3.3	6.0	5.4	4.9	....
23	11.0	13.6	14.8	13.1	3.0	5.7	7.2	5.3	....
24	10.9	12.8	14.2	12.6	3.0	5.0	6.5	4.8	....
25	14.6	14.0	15.6	14.7	10.7	7.8	8.0	8.8	.24
26	13.7	13.8	15.0	14.1	9.2	8.4	7.9	8.5	....
27	13.1	13.6	14.7	13.8	5.1	6.2	7.1	6.1	....
28	12.2	13.6	14.6	13.4	3.5	5.8	6.8	5.3	....
29	11.5	12.8	13.9	12.7	3.0	5.2	6.3	4.8	....
30	19.1	18.6	17.5	18.4	20.1	14.1	11.2	15.1	2.16
31	18.3	19.3	18.0	18.5	15.0	13.2	11.7	13.3	.10
August 1	15.6	18.2	18.6	17.4	11.6	12.3	12.5	12.1	....

This table shows that throughout the season the soil moisture was greater within the tent than without. This difference is well shown in figure 1.

From this it is clear that the tent conserves the moisture in the soil to a marked degree. It does this by checking the evaporation, a point which will be discussed at greater length in this paper.

This difference in soil moisture is of great benefit to plant growth, especially during a protracted drought, as can be seen from Plate III. Figure 1 of this plate shows a field of tented tobacco as it stood on

July 23, after a season of only 3.92 inches rainfall and no rain at all for the preceding eight days. It was in a very healthy and thriving condition. Figure 2 shows a field of outside tobacco photographed on the same day. This tobacco was in a badly wilted condition; the drought had not only stopped its growth, but was causing it to deteriorate.

The difference in the water contents of the soils inside and outside of the tent brought out some interesting observations of the effect of rainfall on a soil under different conditions. An examination of Table I will show that a small amount of rainfall has a greater effect on the moisture of the soil outside than inside the tent. For example, on July 25 a rainfall of 0.24 inch caused an increase of 4 per cent in the moisture of the outside soil, while the increase inside at the same time was only 2.1 per cent. The results are quite similar for other rainfalls.

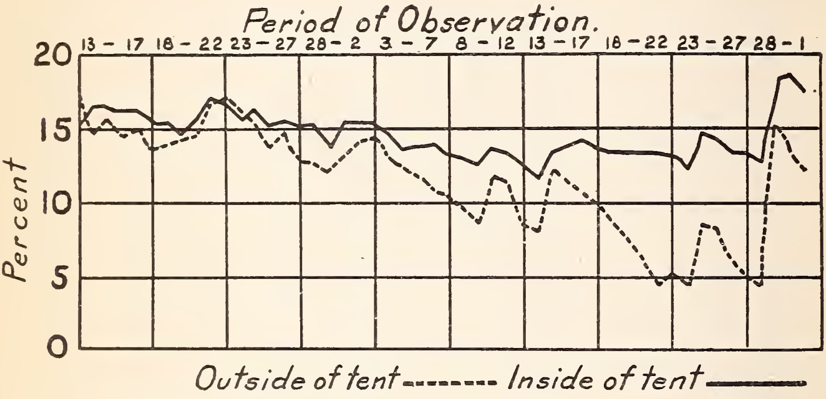
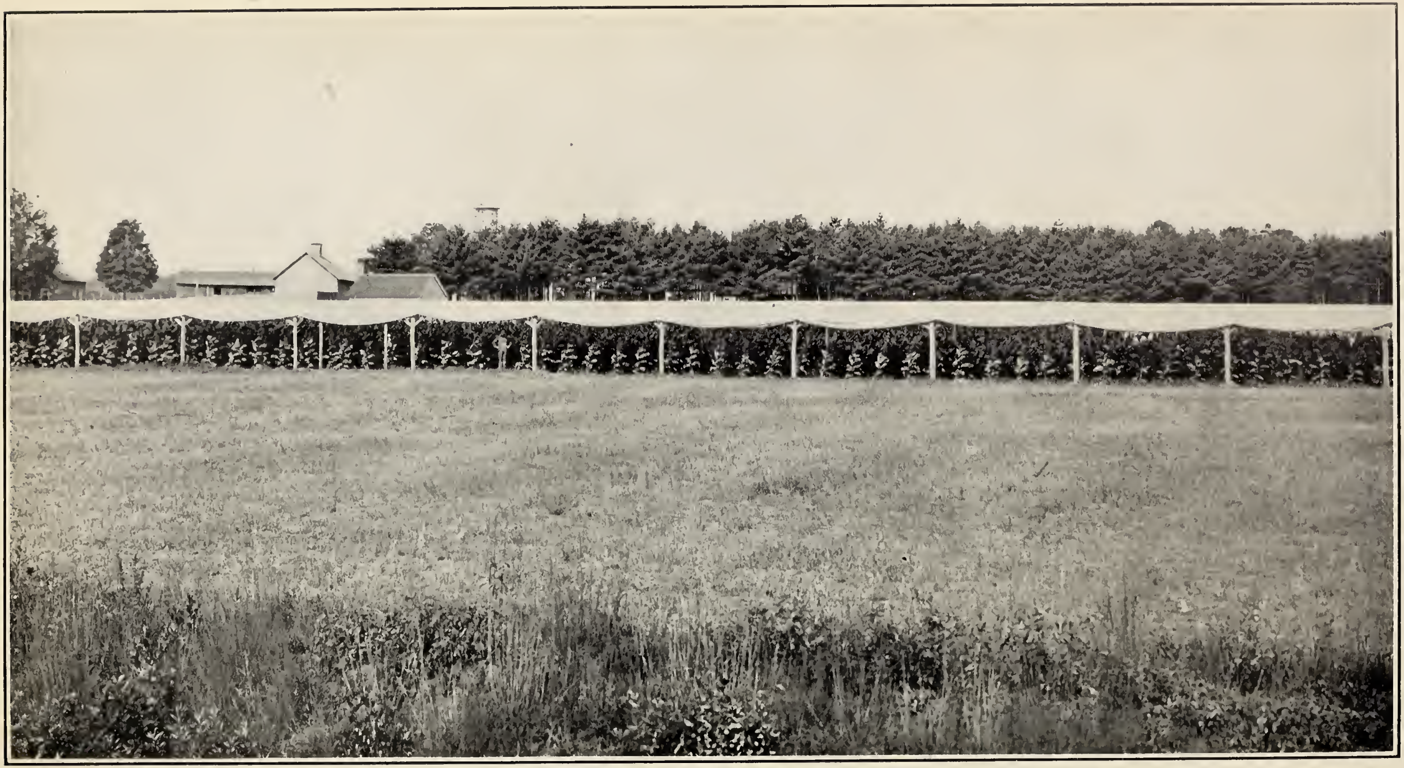


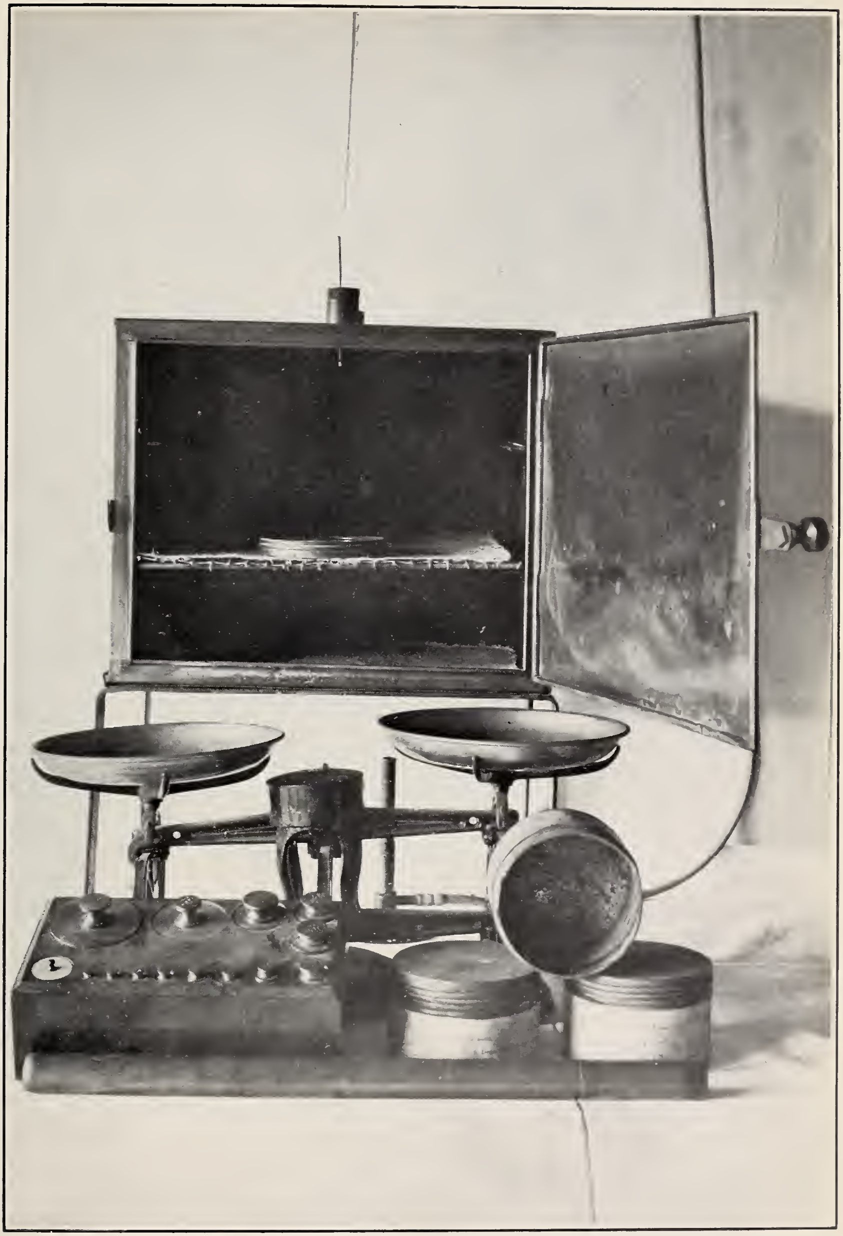
FIG. 1.—Diagram showing relative moisture content of soil inside and outside of tent.

It would appear that this variation is to be attributed directly to the fact that the inside soil is regularly the wetter one, which probably influences the effectiveness of rains in one or both of two ways: (1) Because, being nearer the saturation point, or its maximum water-holding power, the drainage factor is greater, and (2) because the damper soil is probably in better capillary connection with the ground waters, or the water table, so that a rain does not have as great an influence in increasing the capillary rise as it does in a dry soil.

In order to bring out this point better, and to see to what extent changes in soil moisture are due to the rainfall, the effects that should be due to some of the rainfalls have been calculated and in turn compared to the observed effects. We have selected for this only those rainfalls that occurred after several days of dry weather, so that the



EXTERIOR VIEW OF EXPERIMENTAL TENT.



INSTRUMENTS USED IN DETERMINING MOISTURE CONTAINED IN SOIL.

variation in soil moisture could be attributed to the particular rainfalls. Having determined the apparent specific gravity of this soil, containing approximately 10 per cent water, to be about 1.5, the increase that the rainfalls should have caused in 9 inches of soil was calculated. The results are given in Table II.

TABLE II.—*Effect of rainfall on soil moisture.*

Date.	Rainfall.	Inside of tent.				Outside of tent.			
		Moisture in soil before rain.	Actual moisture in soil after rain.	Calculated moisture in soil after rain.	Difference.	Moisture in soil before rain.	Actual moisture in soil after rain.	Calculated moisture in soil after rain.	Difference.
	Inches.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
June 20	0.10	14.9	15.4	15.5	+0.1	14.0	14.4	14.6	+0.2
July 1	.22	13.7	15.6	15.1	− .5	12.1	13.6	13.4	− .2
11	.17	12.7	13.7	13.8	+ .1	8.7	11.8	9.8	−2.0
15	.44	11.8	13.9	14.5	+ .6	8.1	12.2	10.9	−1.3
25	.24	12.6	14.7	14.1	− .6	4.8	8.8	6.4	−2.4
31	2.16	12.7	18.4	24.7	+6.3	4.8	15.1	17.9	+1.2

From this it can be seen that for conditions inside the tent practically enough water was supplied by the rain to account for the increases in the water content of the soil. Within the tent the moisture was so conserved that it was rarely below 11 per cent. When the soil is in this condition the rain seems to have little effect in increasing the soil moisture by causing the ground waters to be drawn up. In a couple of cases the calculated value was about 0.5 per cent below the actual, which variation is, however, about within the limits of error due to inaccuracies and irregularities in taking samples when measuring the soil moisture and the rainfall, and to the approximate calculation.

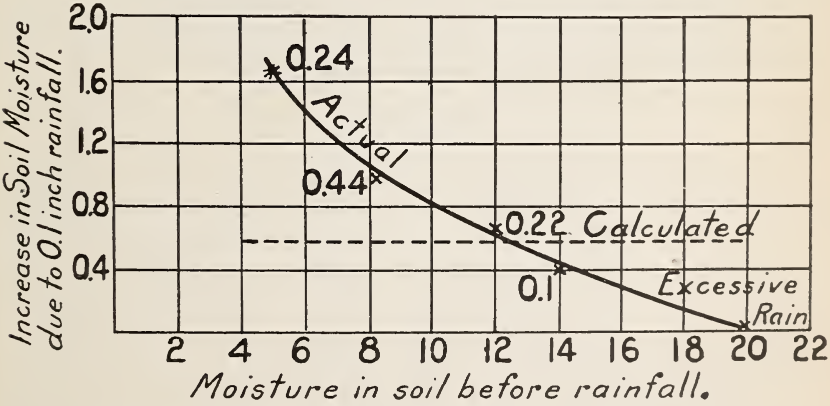


FIG. 2.—Diagram showing effect of the wetness of a soil on the increase in soil moisture due to a definite amount of rainfall.

The amount of rain was likewise sufficient to account for the increase without the tent, when, prior to the rain, the soil contained over 11 per cent of water, as it did before the rains of June 20 and July 1. When the soil was dry, however, this was no longer true. The water furnished by the rain was not enough to cause the increases noted. Additional water must have come from some other source, which could only be from the deeper ground waters.

The relation existing between the previous moisture condition of the soil and the increase due to a definite amount of rain is well shown by figure 2. The curve is plotted from the data showing conditions outside the tent, where there was a considerable variation during the season in the water content of the soil.

The actual increase in soil moisture due to 0.1 inch of the different rainfalls was calculated, and plotted as ordinates; the abscissæ represent in actual per cents the moisture in the soil before rainfall. The amount of rainfall corresponding to the different points are marked with them. The point that shows where additional rain will cause no further increase was taken from Table I for July 30, on which date a very heavy rain fell, and when the top layer must have been completely saturated with water. The theoretical increase is, of course, almost constant, and is represented by the dotted line. In other words, the dotted line represents the increase that the actual water supplied by the rain would cause. Where the actual curve lies above this, extra water was derived from another source, probably the deeper ground waters. Where the actual curve lies below the calculated curve the effect of drainage is indicated.

ATMOSPHERE.

The atmospheric conditions were determined by means of registering bydrometers, thermographs, evaporimeters, and an anemometer (see Pl. IV). The registering hydrographs and thermographs are instruments supplied with clockwork, and need attention only once in seven days. The hydrographs are used for recording the relative humidity of the atmosphere and the thermographs for recording the temperature. One of each of these instruments was placed inside and outside of the tent. The records were checked every day; the hydrometer with Green's sling psychrometer, and the thermograph with a standard thermometer, and corrections made when necessary. From these records tables were made for comparison and study by taking the maximum and minimum points reached in each twenty-four hours. The temperature table is as follows:

TABLE III.—*Temperature of atmosphere inside and outside of tent, season 1905.*

Date.	Inside of tent.				Outside of tent.				Difference between inside and outside of tent.			
	Maximum.	Minimum.	Difference.	Mean.	Maximum.	Minimum.	Difference.	Mean.	Maximum.	Minimum.	Difference.	Mean.
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
June 13	83	56	27	69.5	82	56	26	69.0	1	0	1	0.5
14	85	52	23	68.5	83	54	29	68.5	2	−2	4	.0
15	90	56	34	73.0	89	57	32	73.0	1	−1	2	.0
16	89	61	28	75.0	87	63	24	75.0	2	−2	4	.0
17	86	68	18	77.0	86	70	16	78.0	0	−2	2	−1.0
18	90	60	30	75.0	89	60	29	74.5	1	0	1	.5
19	66	51	15	58.5	63	50	13	56.5	3	1	2	2.0
20	63	58	5	60.5	61	57	4	59.0	2	1	1	1.5
21	72	62	10	67.0	72	62	10	67.0	0	0	0	.0
22	85	68	17	76.5	81	67	14	74.0	4	1	3	2.5
23	87	60	27	73.5	81	60	21	70.5	6	0	6	3.0
24	81	47	34	64.0	81	47	34	64.0	0	0	0	.0
25	88	61	27	74.5	85	61	24	73.0	3	0	3	1.5
26	90	52	38	71.0	89	52	37	70.5	1	0	1	.5
27	73	49	24	61.0	70	50	20	60.0	3	−1	4	1.0
28	80	51	29	65.5	76	51	24	63.5	4	0	5	2.0
29	88	47	41	67.5	84	47	37	65.5	4	0	4	2.0
30	92	57	35	74.5	88	58	30	73.0	4	−1	5	1.5
July 1	81	63	18	72.0	79	63	8	71.0	3	0	−1	1.0
2	70	66	4	68.0	70	65	5	67.5	0	1	3	.5
3	92	58	34	75.0	88	57	31	72.5	4	1	2	2.5
4	93	56	37	74.5	90	55	35	72.5	3	1	3	2.0
5	86	64	22	75.0	82	63	19	72.5	4	1	1	2.5
6	90	68	22	79.0	87	66	21	76.5	3	2	2	2.5
7	90	68	22	79.0	87	67	20	77.0	3	1	1	2.0
8	93	71	22	82.0	91	70	21	80.5	2	1	4	1.5
9	98	64	34	81.0	93	63	30	78.0	5	1	2	3.0
10	96	64	32	80.0	93	63	30	78.0	3	1	3	2.0
11	95	70	25	82.5	92	70	22	81.0	3	0	2	1.5
12	95	73	22	84.0	92	72	20	82.0	3	1	3	2.0
13	93	69	24	81.0	90	69	21	79.5	3	0	3	1.5
14	94	65	29	79.5	91	65	26	78.0	3	0	2	1.5
15	87	49	38	68.0	84	48	36	66.0	3	1	2	2.0
16	87	67	20	77.0	84	66	18	75.0	3	1	2	2.0
17	99	67	32	83.0	97	67	30	82.0	2	0	2	1.0
18	100	66	34	83.0	98	66	32	82.0	2	0	2	1.0
19	98	61	37	79.5	94	61	33	77.5	4	0	4	2.0
20	90	54	36	72.0	87	54	33	70.5	3	0	3	1.5
21	86	48	38	67.0	83	47	36	65.0	3	1	1	2.0
22	85	55	30	70.0	83	55	28	69.0	2	0	2	.5
23	74	60	14	67.0	72	60	12	66.0	2	0	2	1.0
24	78	60	18	69.0	74	58	17	66.0	4	2	1	3.0
25	83	45	38	64.0	69	45	34	57.0	4	0	4	7.0
26	83	43	40	63.0	81	43	38	62.0	2	0	2	1.0
27	87	49	38	68.0	85	48	37	66.5	2	1	1	1.5
28	88	60	28	74.0	88	60	28	74.0	0	0	0	.0
29	84	67	17	75.5	83	66	17	74.5	1	1	0	1.0
30	82	62	20	72.0	79	61	18	70.0	3	1	2	2.0
31	74	58	16	66.0	71	58	13	64.5	3	0	3	1.5
Aug. 1	78	48	30	64.0	76	47	29	61.5	2	1	1	2.5
2	86	48	38	67.0	84	48	36	66.0	2	0	2	1.0
3	87	48	39	67.5	83	48	35	66.5	4	0	4	1.0
4	86	66	20	76.0	85	65	20	75.0	1	1	0	1.0
5	86	67	19	76.5	86	66	20	76.0	0	1	−1	.5
6	86	59	27	72.5	83	59	24	71.0	3	0	3	1.5
7	91	56	35	73.5	89	56	33	72.5	3	0	2	1.0
8	84	62	22	73.0	82	62	20	72.0	2	0	2	1.0
9	79	66	13	72.5	77	65	12	71.0	2	1	1	1.5
10	85	72	13	78.5	82	72	10	76.0	3	0	3	2.5
11	91	73	18	82.0	91	72	19	81.5	0	1	−1	.5
12	86	71	15	78.5	85	71	14	78.0	1	0	−1	.5
13	88	56	32	72.0	86	56	30	71.0	2	0	2	1.0

This table shows that the temperature of the atmosphere in the tent was from 1° to 3° above the normal throughout the season and that the greatest variation was during the heat of the day.

Although there was never a difference of more than 3° in temperature, the atmosphere of the tent felt more humid and tropical. As the greatest difference was registered on bright days and at the maximum temperature of the day, it is apparent that the cloth produces much the same effect as does glass, only in a lesser degree. The moist tropical effect is caused by the humidity of the atmosphere and the low wind velocity, subjects which will be discussed in their proper places.

In order to assist in making the above numerical table more clearly understood, a diagram (fig. 3) is presented. This figure is self-explanatory, and readily shows the effect a tent has on the temperature from day to day.

The relative humidity of the atmosphere was recorded as described above by the recording hydrometer. In order to substantiate the records of the hydrometer, a short test of the relative dryness of the atmosphere between the inside and outside of the tent was made with evaporimeters. (See Pl. IV.)

The evaporimeter is a small graduated glass tube, one end of which is sealed and the other furnished with a metallic clasp, which holds a disk of filter paper, supported by a glass plate close to the mouth of the tube. After the tube has been filled with water, it is inverted, so that the open end in contact with the filter paper is downward.

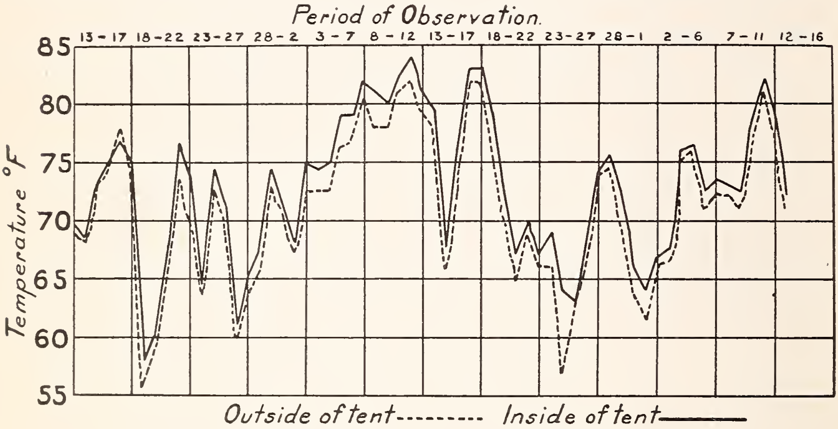


FIG. 3.—Diagram showing temperature inside and outside of tent.

The evaporation of the water takes place through the filter paper, and the amount of evaporation is recorded by the graduations on the tube.

One of these instruments was placed inside the tent, and one outside for a few days only, namely, from July 18 to July 23, inclusive, with the following results:

Readings of evaporimeter inside and outside of tent.

Date.	Inside of tent.	Outside of tent.	Difference.	Date.	Inside of tent.	Outside of tent.	Difference.
	C. c.	*C. c.*	*C. c.*		*C. c.*	*C. c.*	*C. c.*
July 18	5	12	7	July 21	8.5	21	12.5
19	7	16	9	22	9	24	15
20	8	19	10	23	7	17	10

Errata—For hydrograph and hydrometer read hygrograph and hygrometer.

This table shows that the evaporation of water under outside conditions was more than twice as great as it was in the tent, which fully agrees with the relative humidity records given by the recording hydrometer. From the results of the hydrometer measurements a table of relative humidity was made in the same way as the table of temperatures.

TABLE V.—*Relative humidity of atmosphere inside and outside of tent, season 1905.*

Date.	Inside of tent.				Outside of tent.				Difference between inside and outside of tent.				
	Maximum.	Minimum.	Difference.	Mean.	Maximum.	Minimum.	Difference.	Mean.	Maximum.	Minimum.	Difference.	Mean.	Rainfall.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Inches.*
June 23	93	63	30	78.0	94	66	28	80.0	−1	−3	2	−2.0	0.17
24	93	47	46	70.0	93	48	45	70.5	0	−1	1	− .5	....
25	96	54	42	75.0	94	55	39	74.5	2	−1	3	.5	....
26	95	53	42	74.0	92	53	39	72.5	3	0	3	1.5	....
27	92	54	38	73.0	91	57	34	74.0	1	−3	4	−1.0	....
28	96	50	46	73.0	92	54	38	73.0	4	−4	8	.0	....
29	97	44	53	70.5	95	45	50	70.0	2	−1	3	.5	....
30	97	43	54	70.0	97	35	62	66.0	0	8	−8	4.0	....
July 1	94	62	32	79.0	93	55	38	74.0	1	7	−6	5.0	.22
2	93	79	14	85.5	93	70	23	81.5	0	9	−9	4.0	....
3	94	48	46	71.0	82	42	40	62.0	12	6	6	9.0	.03
4	93	47	46	70.0	82	38	44	60.0	11	9	2	10.0	....
5	93	57	36	75.0	83	50	33	66.5	10	7	3	8.5	....
6	93	59	34	76.0	83	54	29	73.5	10	5	5	2.5	....
7	92	60	32	76.0	82	53	29	67.5	10	7	3	8.5	....
8	93	60	33	76.5	83	55	28	69.0	10	5	5	7.5	....
9	91	54	37	72.5	82	47	35	64.5	9	7	2	8.0	....
10	93	56	37	74.5	83	48	35	65.5	10	8	2	9.0	....
11	92	60	32	76.0	84	54	30	69.0	8	6	2	7.0	.17
12	92	58	34	75.0	83	53	30	68.0	9	5	4	7.0	....
13	86	58	28	72.0	82	54	28	68.0	4	4	0	4.0	....
14	88	53	25	70.5	83	48	25	65.5	5	5	0	5.0	....
15	90	52	38	71.0	85	44	41	64.5	5	8	−3	6.5	.44
16	90	47	43	68.5	85	41	44	63.0	5	6	−1	5.5	....
17	88	55	33	76.5	82	48	34	65.0	4	7	−1	11.5	....
18	92	50	42	71.0	84	44	40	64.0	8	6	2	7.0	....
19	92	58	34	75.0	84	50	34	67.0	8	8	0	8.0	....
20	93	50	43	71.5	85	42	43	63.5	8	8	0	8.0	....
21	94	48	46	71.0	85	38	47	61.5	9	10	−1	9.5	....
22	94	50	44	72.0	85	40	45	62.5	9	10	1	9.5	....
23	92	65	27	78.5	82	58	24	70.0	10	7	3	8.5	....
24	92	81	11	86.5	81	75	6	78.0	11	6	5	8.5	....
25	93	51	42	72.0	84	43	41	63.5	9	8	1	8.5	.24
26	93	48	45	70.5	84	39	45	61.5	9	9	0	9.0	....
27	94	47	47	70.5	85	35	50	60.0	9	12	−3	10.5	....
28	94	49	45	71.5	85	37	48	61.0	9	12	−3	10.5	....
29	93	64	29	78.5	84	55	29	69.5	9	9	0	9.0	....
30	93	69	24	82.0	83	63	20	73.0	10	6	4	9.0	2.16
31	92	70	22	81.0	82	65	17	73.5	10	5	5	7.5	.10
Aug. 1	93	60	33	76.5	83	53	30	68.0	10	7	3	8.5	....
2	93	50	43	71.5	82	39	43	65.5	11	11	0	6.0	....
3	94	46	48	70.0	83	35	48	59.0	11	11	0	11.0	....
4	93	60	33	76.5	83	48	35	65.5	10	12	−2	11.0	....
5	92	57	35	74.5	82	48	34	65.0	10	9	1	9.5	....
6	93	67	26	80.0	83	59	24	71.0	10	8	2	9.0	....
7	92	60	32	76.0	82	50	32	66.0	10	10	0	10.0	.44
8	93	68	25	80.5	82	58	24	70.0	11	10	1	10.5	....
9	92	77	15	84.5	82	68	14	75.0	10	9	1	9.5	.58
10	92	73	19	82.5	82	63	19	72.5	10	10	0	10.0	....
11	92	68	24	80.0	82	59	23	70.5	10	9	1	9.5	....
12	92	76	16	84.0	83	68	15	75.5	9	8	1	8.5	....
13	92	61	31	76.5	82	50	32	66.0	10	11	−1	10.5	....
14	93	55	38	74.0	84	42	42	63.0	9	12	−4	11.0	....

The results tabulated above are shown graphically in figure 4.

Errata.—For hydrograph and hydrometer read hygrograph and hygrometer

The above table, which represents the relative amount of water vapor in the atmosphere, inside and outside of the tent, for fifty-three consecutive days, shows that the moisture was much greater inside the tent than outside during nearly the whole season. One cause of this is that the tent tends to prevent the water which is given off in transpiration from escaping. The amounts of water thus given off are known to be large. Since it is retained more or less in the atmosphere surrounding the plants it would have a marked effect on the relative humidity.

The fact that the tent retains this water vapor is due largely to the protection it gives against the wind. It is well known that the evaporation of water depends to a great extent on the velocity of the wind, because the wind affects the relative humidity of the surrounding air by replacing the vapor-charged atmosphere with fresh air. For this reason the anemometer records have a direct bearing on the relative humidity of the atmosphere.

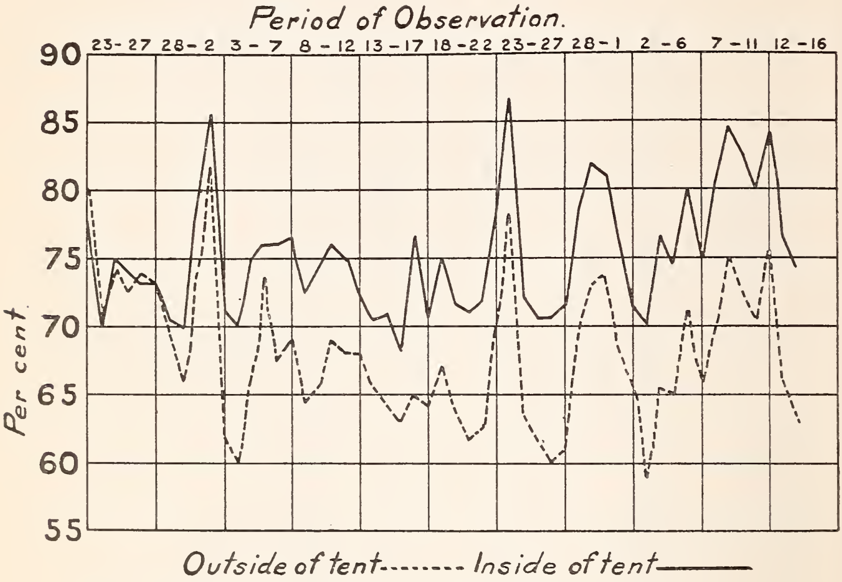


FIG. 4.—Diagram showing relative humidity inside and outside of tent.

If the wind movement was not more than 5 miles an hour outside the tent, the anemometer inside the tent was not affected, and when it blew almost a gale in the open field there was just a slight breeze in the tent. The difference in wind movement is shown in the following table:

Velocity of wind inside and outside the tent.

[Miles per hour.]

Date.	Inside of tent.	Outside of tent.	Difference.
June 27	3.0	20.0	17.0
28	1.0	10.0	9.0
July 13	.7	9.0	8.3
15	.5	7.0	6.5

We have separately presented the data that show the influence of a tent on soil moisture, temperature of the air, relative humidity, and velocity of the wind, and discussed somewhat the part the tent played in each of these cases. Not only does the tent affect each of these directly, but indirectly as well, for some of these in turn have an influence on each other.

The variables are so many that it is quite impossible to bring out sharp correlations between the different factors. However, some relations are suggested. It was shown that the moisture of the soil within the tent was higher throughout the season than in the outside soil, which difference was attributed to decrease in evaporation. It was then shown that the temperature within the tent was a little higher than outside, which in itself would tend to increase evaporation at the surface of the soil and to dry it out faster. With the increase in temperature, however, there is recorded a decrease in wind movement, and consequently an increase in humidity, which so checks the evaporation that it more than offsets the influence of temperature. The temperature difference between the inside and outside of the tent is probably almost entirely due to the blanketing effect of the cloth, although the more rapid evaporation outside would tend to lower the temperature somewhat, since evaporation is accompanied by an absorption of heat.

The difference in velocity of wind outside and inside of course is important, for if the inside air was rapidly changing the warmer air under the cloth would be swept away and replaced by the cooler air from outside.

We then find that the tent markedly affects the soil and atmospheric conditions. It affects the atmosphere by, first, slightly increasing the temperature; second, by increasing the relative humidity a great deal, and, third, by reducing the velocity of the wind. The last two of these reduces evaporation at the soil surface, which conserves the soil moisture and maintains the soil more nearly at the optimum water content.

Each of these changes must have its effect on plant growth. In this temperate zone the atmosphere is scarcely ever too hot or too humid during the growing season for the best development of tobacco plants. The successful introduction of a plant from a warmer and more humid climate requires either a change in the nature of the plant or a modification of the climatic conditions to simulate its native environment. This modification may be slight, as is shown above, but its effect is apparent, as is demonstrated in the following comparison of the growth of tobacco plants inside and outside the shade:

PLANT GROWTH.

It is stated in the introduction to this bulletin that practical experiments have proved that plants grow faster and mature earlier when grown in cloth shades than when grown under normal conditions. In the present experiments a careful record was kept of the growth of plants from day to day, both inside and outside of the tent. The procedure was as follows: When the plants were set, a stake 8 feet long was driven into the ground close to each plant selected for measurement. A notch was made in each stake to serve as a base from which to take measurements. By the use of a try square the height of the buds of the plants were marked on the stakes each day and measured. These measurements were taken until the plants had reached maturity.

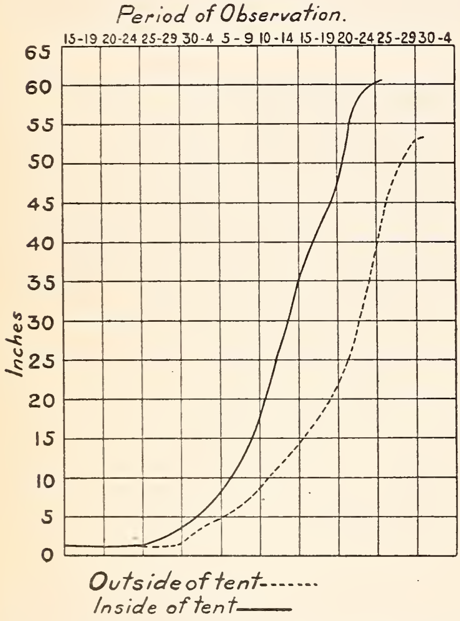


FIG. 5.—Diagram comparing rate of growth in broadleaf tobacco inside and outside of tent.

In order to avoid the possibility of a break in the records resulting from the death of the plants under observation, 10 plants of each variety, Broadleaf and Havana seed, were used in the tests. The average growth of each group of 5 plants is shown graphically in diagrams (figs. 5, 6, and 7). These diagrams show very plainly that the plants in the tent grew faster, larger, and matured at an earlier date than did the plants in the open, but while the plants grew faster and the leaves larger the yield per acre of these two varieties was less by from 100 to 300 pounds inside the tent than outside. This was

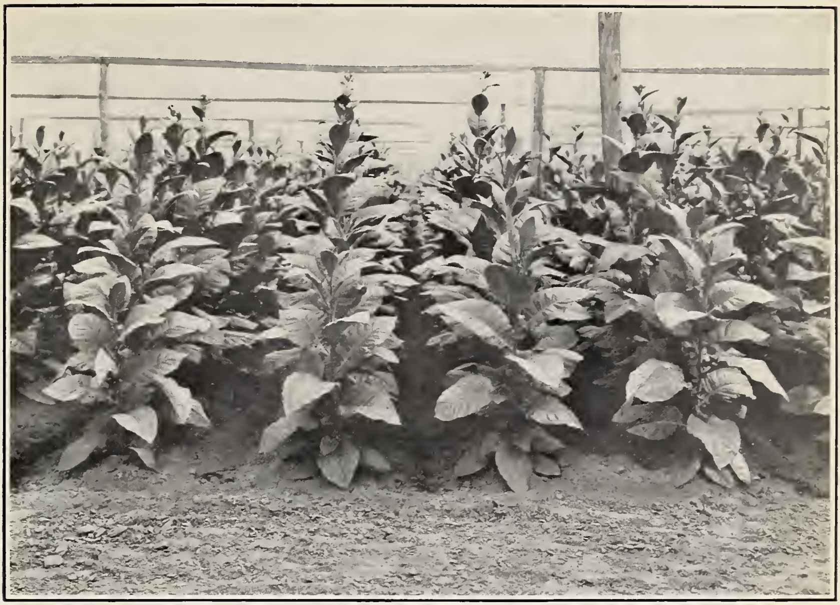


FIG. 1.—INSIDE EXPERIMENTAL TENT, SHOWING THE FINE CONDITION OF THE TOBACCO DURING A DROUGHT, DUE TO THE EFFECT OF THE CLOTH SHADE IN PRESERVING THE SOIL MOISTURE.

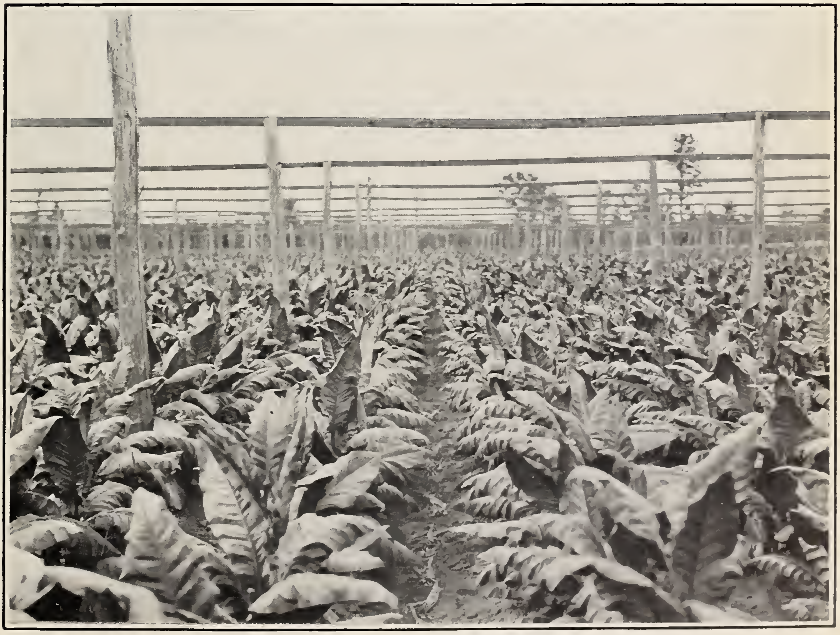


FIG. 2.—OUTSIDE TOBACCO WILTED FROM THE EFFECTS OF A DROUGHT.

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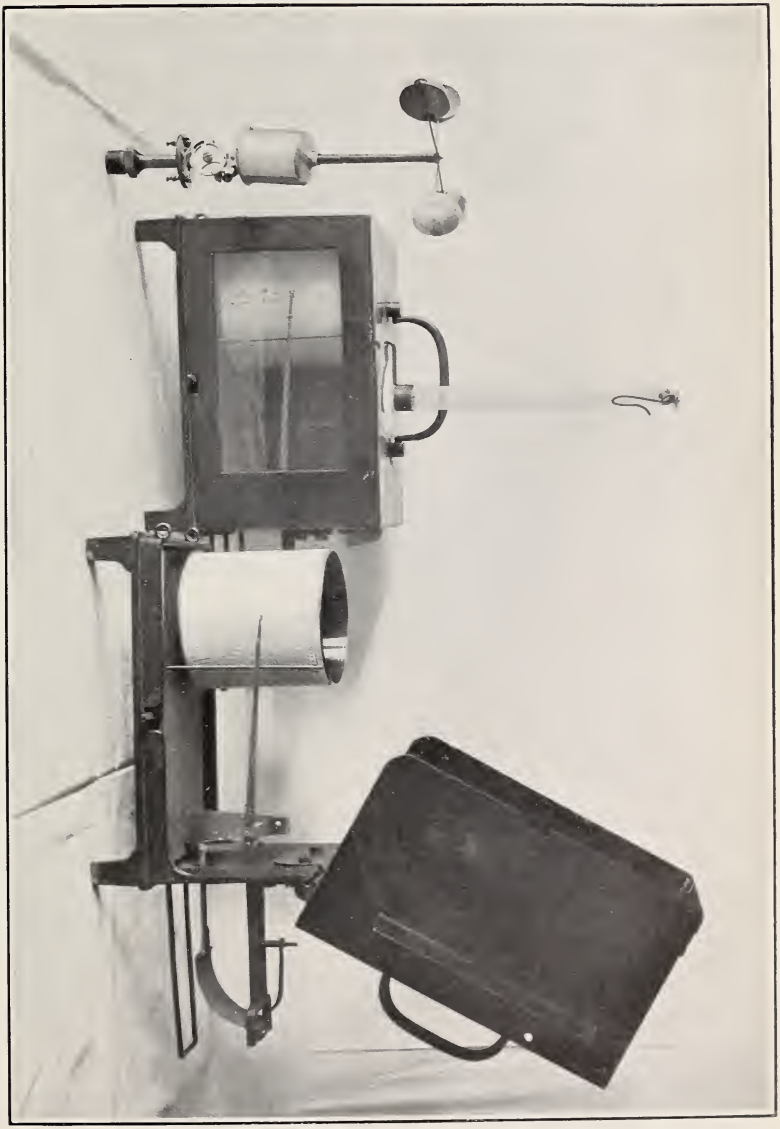

INSTRUMENTS USED IN DETERMINING TEMPERATURE, HUMIDITY, AND WIND MOVEMENT.

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probably due to the influence of the shade, which tends to make the surface of the leaves larger but at the same time much thinner.

During the season 10 Sumatra and 10 Cuban plants were measured as described above, and 5 of each selected from which to get the average growth. This was not done for the purpose of comparison with the plants grown under outside conditions, because in this climate these types are seldom grown in the open, but rather to show the rapidity with which they grow, and the height they attain.

The plants from all varieties measured were set out about the same time, namely, between the 15th of May and the 1st of June, except the Broadleaf, which was set after June 1. As the plants did not make any bud growth until after June 10, no measurements were recorded until after that time.

The first two or three weeks after a tobacco plant has been transplanted from the seed bed to the field is occupied by the plant in recovering from the shock of removal, getting rerooted, and making a slight leaf growth. From this time on, however, the plant, if healthy and well cultivated and the land rich, moist, and warm, makes a very rapid growth.

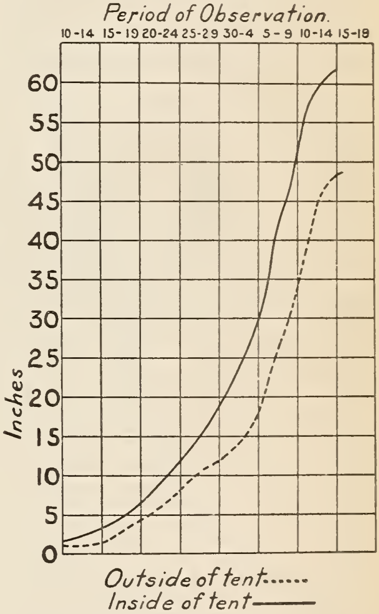

Fig. 6.—Diagram comparing rate of growth of Havana seed tobacco.

CONCLUSION.

It has been shown in this paper that the tent has the following effects on the soil, atmosphere, and plant growth:

(1) The soil retains more moisture, which is of especial importance during the dry periods. The inside soil is then always closer to the optimum water content. Because the soil is not subject to the packing due to alternate wetting and drying, it remains in better physical condition.

(2) The temperature of the atmosphere is made slightly warmer, which brings the temperature closer to the optimum growing temperature. An even greater effect is, however, perhaps due to the fact that there is less variation in the temperature, which is generally recognized to be of much importance.

(3) The relative humidity of the atmosphere is greatly increased. In addition to its effect on soil and atmospheric conditions it has an influence on plant growth. This, according to Strasburger, Noll, Schenck, and Schimper,[a] is twofold. "It acts as a stimulus, and also, by diminishing transpiration, increases turgidity." This is a very interesting point and substantiates the connection between the relative humidity and plant growth, as is shown in the records already given.

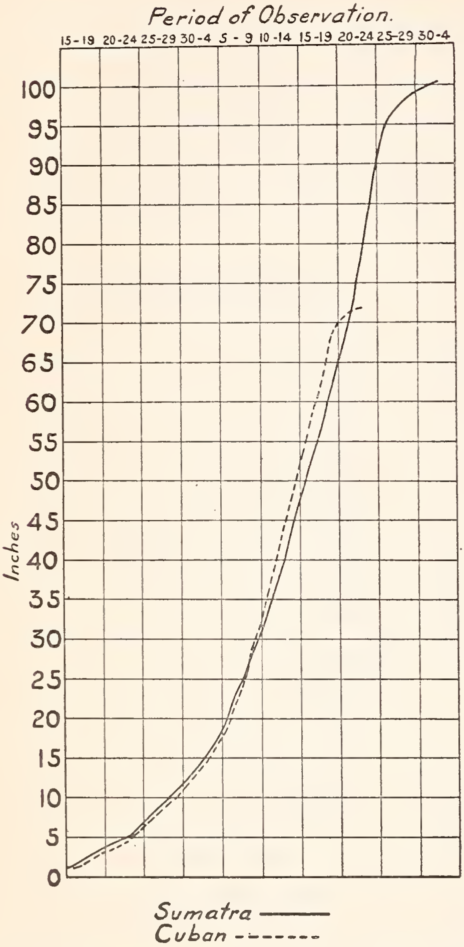

FIG. 7.—Diagram comparing rate of growth of Sumatra and Cuban seed tobacco.

(4) The velocity of the wind is much reduced, which decreases evaporation, and is of importance in the preservation of the plants, for they are not whipped, bruised, or blown down.

(5) The plants make a larger, more rapid, and earlier growth. These are the results that induce and make it profitable for the tiller of the soil to go to the expense of erecting the tent.

The effect that a tent has on the soil, atmosphere, and plant growth has been plainly shown by the tables presented, and their connections, one with another, discussed. In conclusion, however, the following recapitulary table will present more forcibly the degree to which the climate for a whole season is modified by artificial means.

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[a] Text-book of Botany.

Comparative statement of conditions of temperature, soil moisture, and relative humidity, inside and outside of tent.

Observations.	Average soil moisture for season.	Average temperature for season.	Average relative humidity for season.
	Per cent.	°*F.*	*Per cent.*
Inside of tent	14.7	72.8	79.0
Outside of tent	11.6	71.4	71.7
Difference	3.1	1.4	7.3

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